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Microstructural, cooking and textural characteristics of potato (*Solanum tuberosum* L) tubers in relation to physicochemical and functional properties of their flours†

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Abstract: Potato tubers from six different cultivars were freeze-dried, ground into flour and analyzed for thermal, pasting and textural characteristics (using differential scanning calorimetry, Rapid Visco analyzer and Instron universal testing machine, respectively) to study the relationship between flour characteristics and cooked potato mealiness. The potatoes with higher sensory mealiness scores resulted in flours having lower transition and pasting temperatures, higher amylose content, setback, peak and final viscosity. The flour gels from the mealier potatoes also exhibited higher values of textural parameters such as hardness, cohesiveness, chewiness and springiness. The microstructure of the tuber parenchyma (studied using scanning electron microscopy), cooking and sensory characteristics of potatoes were found to be related to the pasting and textural characteristics of their flours. Potato cultivars with lower mealiness scores, loosely packed cell arrangement, with comparatively large-size cells and thinner cell walls showed lower values of textural parameters for both raw and cooked potatoes. This information may prove useful for the selection of potato cultivars with desirable textural and flour-making properties for specific end-uses.

Keywords: potato; *Solanum tuberosum*; tuber; cultivars; texture; flour; microstructure; mealiness; pasting; thermal; starch; gels

INTRODUCTION

Structure and properties of the cell wall polymers have been reported to influence the way in which the plant tissues undergo mechanical deformation and failure during mastication.[1] In potatoes (*Solanum tuberosum* L), the abundance of starch in the cells and the shape and size of the starch granules have been reported as being important for the final texture,[2–4] as has the structure of the cell wall polymers.[5,6] Andersson *et al*[7] have provided a summary of factors that have been reported to influence cooked potato texture: tissue total solids, starch content, starch granule size, parenchyma cell size, pectic substance nature and content etc. Kalab *et al*[8] reported that the microstructural features directly influence the textural characteristics of the plant food materials. Therefore, a good understanding of texture requires an adequate knowledge of food structure and how it reacts against an applied perturbation. When the force is applied to this structure, accepted to be a network of interconnected cells, a failure or rupture occurs at the point of minimum resistance. In this system, either the cells can separate through the middle lamella or the cells can burst, depending upon the strength of the middle lamella. Usually, raw potatoes present cell rupture, while cooked ones show cell separation as a result of thermal destabilization of pectic materials.[9] Textural changes occurring during thermal processing and cooking in potatoes and potato products are mainly associated with the gelatinization and retrogradation behaviour of starch, which represents the predominant substance in the tuber[3,10–14] cell wall and middle lamellae structural components.[6,14,15] During industrial production of

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frozen French fries, potato chips, blanched cubes, mashed potatoes and many other cooked products, the original material is subjected to a variety of thermal treatments. The optimization of these industrial processes requires a deep knowledge of starch gelatinization. Pravisani *et al*[16] studied the kinetics of starch gelatinization in potato tubers using differential scanning calorimetry (DSC). Barrios *et al*[17] found that the mealy potatoes had higher specific gravities, starch and amylose content as well as a higher percentage of large starch granules (diameter $>50\,\mu$m) than the least mealy cultivars. This variation in potato tubers is mainly responsible for the variation in the final product. As no single potato cultivar has been shown to be appropriate for all food applications,[18] screening of the cultivars is needed for specific end use and for their ability to provide optimum processing performance and product quality.[19] Processed potato products, especially potato flour, are highly versatile in manufacturing convenience foods. They have their own distinctive flavor and texture but are sufficiently bland to be incorporated easily into traditional local preparations.[20] The functional characteristics of the flour could depend, among other factors, on the type of tuber as well as the processing methods. Kulkarni *et al*[20] compared two Mauritian potato varieties in terms of flour quality and their use in some traditional foods. Willard and Englar[21] studied the viscosity of potato flour using a Brookfield viscometer as well as viscoamylograph and reported that the viscosity increased as the screen size decreased. The majority of the reported work has involved the physicochemical and functional properties of potato starches rather than the flour itself, with the exception of a recent report on the pasting behavior of whole-tissue flours by Higley *et al*,[19] who reported that rapid viscosity analysis could prove useful for detecting subtle differences in the cultivar pasting characteristics corresponding to cooked potato texture. It is necessary to analyze the rheological, thermal and textural properties of potato flours from different Indian cultivars, since these could be incorporated in the preparation of a diverse range of traditional products.

The purpose of this investigation was to study the microstructural, cooking and textural characteristics of potatoes from different Indian potato cultivars in relation to thermal, pasting and textural properties of their flours.

EXPERIMENTAL

Materials

The tubers (*Solanum tuberosum* L) of Kufri Bahar, Kufri Ashoka, Kufri Kanchan, Kufri Kunden, Kufri Dewa and Kufri Lalima cultivars were procured from Central Potato Research Station, Shimla, India from the 2002 harvest. Uniform-sized tubers were selected from each cultivar and washed thoroughly. The osmic acid and sodium cacodylate were purchased from Central Drug House (P) Ltd, New Delhi (India), while gluteraldehyde (solution 25%) was obtained from Thomas Baker (chemicals) Ltd, Mumbai (India). All the chemicals used in this study were of analytical grade.

Moisture content

Dry matter content of the potato tubers and moisture content of potato flours were determined in triplicate using a halogen moisture analyzer (Mettler Toledo, Greifensee, Switzerland).

Color characteristics of raw potatoes

Color measurements of the tubers from different potato cultivars were carried out in triplicate using a Hunter colorimeter model D25 optical sensor (Hunter Associates Laboratory Inc., Reston, VA, USA) on the basis of L^*, a^* and b^*. The instrument (45°/0° geometry, 10° observer) was calibrated against a standard red colored reference tile ($L^* = 25.80$, $a^* = 29.25$, $b^* = 12.11$). Three tubers from each cultivar were washed and their periderm was peeled with a knife. The peeled tubers were split into halves and Hunter L^*, a^* and b^* values at the cleaved surface of the potato tubers were measured. The peeled and cut potatoes from each cultivar were evaluated for the development of discoloration after 30 min. The changes in L^*, a^* and b^* values during 30 min storage ($\Delta L = L_{ST} - L_0$, $\Delta a = a_{ST} - a_0$ and $\Delta b = b_{ST} - b_0$, where L_0, a_0 and b_0 represent the readings at time zero, and L_{ST}, a_{ST} and b_{ST} represent the individual readings after storage) associated with enzymatic browning were calculated from the data. The total color difference (ΔE) was evaluated using

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{1}$$

Scanning electron microscopy of raw potatoes

For scanning electron microscopy (SEM), small pieces of perimedullary tissue about 0.2 cm on any one side were cut with a razor blade, fixed in 4% gluteraldehyde (0.1 M sodium cacodylate buffer, pH 7.0) for 24 h, and rinsed with the buffer three times for 15 min each. The samples were then placed in 1% OsO_4 for 24 h, washed with the same buffer three times, 15 min each, and dehydrated by successively washing in an acetone series and finally in amylacetate and then were critical point dried. The samples were glued to SEM target stubs with double-sided adhesive tape, coated with gold–palladium (60:40) and examined in a Jeol JSM-6100 (Tokyo, Japan) SEM operated at 20 kV.

Cooking and textural properties of potatoes

Sample preparation

The tubers were washed and the periderm peeled with a knife. Each tuber was cut into two equal halves. From each half, four cylindrical pieces were taken from the perimedullary parenchyma using a cork borer (diameter 1 cm) and trimmed to a height of 1 cm.

Cooking and textural properties

The cooking time, water uptake and total solids loss during cooking and textural properties of potatoes were determined as described earlier.[11] The cooking time was determined by cooking the cylindrical pieces in boiling distilled water. An aluminum foil was used to cover the beaker during cooking to avoid evaporation losses. After every 2 min of cooking, each cylindrical piece was tested for compression on Instron Universal Testing Machine (Model-4464, Instron, Buckinghamshire, UK). A flat probe (3.5 cm diameter) travelled a distance of 5 mm at a crosshead speed of 50 mm min^{-1}. The compression distance was 50% of the total height of the cylindrical piece. The cooking time was determined as the time required to reach the lowest compression force during 50% compression of the sample. This procedure was replicated three times for each cultivar. For the determination of the water uptake and total solids loss during cooking, the pre-weighed cylindrical pieces were cooked in boiling water for 30 min. The cylindrical pieces were drained and rinsed with distilled water and redrained for 2 min. The cooked cylindrical pieces were weighed for the determination of water uptake (%). The rinse water was collected in a pre-weighed Erlenmeyer glass beaker and placed in an air oven at 110 °C for 24 h. The residue was weighed and reported as total solid loss (percentage weight of the cylindrical piece of potato).

Texture profile analysis (TPA) of the raw and cooked (for 30 min in boiling distilled water) potato cylinders from each cultivar was performed in triplicate using an Instron universal testing machine. The sample was compressed with a cylindrical probe (3.5 cm diameter) using a 10 kg load cell. The sample was preloaded with 0.5% of the total load. The crosshead speed was 15 mm min^{-1} and the deformation was 75% of the original length. The seven textural parameters as modified by Szczesniak[22] were determined from each curve.

Sensory analysis

For sensory analysis, the cylindrical potato pieces were cooked as described for TPA. The sensory analysis was performed on the cooked potatoes by a trained panel of 10 assessors and evaluated on a scale from 0 to 3. The panel was trained for 6 hr prior to the sensory evaluation. The assessors had experience in sensory evaluation of cooked potatoes from previous evaluations.[11] The measurements were performed as described by McComber *et al*[23] using the average of 10 assessors times four sensory replicates. The degree of mealiness was the only characteristic judged. A score of 0 indicated a non-mealy potato; 1 a slightly mealy potato; 2 a moderately mealy potato and 3 a very mealy potato.

Potato flour preparation

Potato dry matter was obtained by freeze-drying. The cylindrical pieces (1 × 1 cm) from the perimedullary region of potato tuber were lyophilized and immediately ground to pass through the sieve number 72 (British Sieve Standards). The powdered samples were then stored in a desiccator over phosphorus pentaoxide until further use.

Physicochemical properties of potato flours

Amylose content, water absorption index (WAI) and water solubility index (WSI)

Amylose content of the potato flours from different cultivars was determined using the method of Williams *et al*.[24] Flour suspension (2%, w/w) was heated in a water bath for 30 min with constant stirring. The gelatinized flour paste was then centrifuged at $3000 \times g$ for 10 min. WAI and WSI of the potato flour pastes were determined as described previously.[25]

Transmittance (%)

A 1% aqueous suspension of flour from each potato cultivar was heated in a water bath at 90 °C for 1 h with constant stirring. The suspension was cooled for 1 h at 30 °C. The samples were stored for 7 days at 4 °C in a refrigerator and transmittance was determined every 24 h by measuring absorbance at 640 nm against a water blank with a Spectronic- 20D (Milton Roy Company, Ivyland, PA, USA).

Differential scanning calorimetry of potato flours

Thermal properties of the samples were analyzed using a DSC-821^{e} (Mettler Toledo, Greifensee, Switzerland) equipped with a thermal analysis data station as described earlier.[26] Flour (3.5 mg, dry weight) was loaded into a 40 µl capacity aluminum pan (Mettler, ME-27 331) and distilled water was added with the help of a Hamilton microsyringe to achieve a starch–water suspension containing 70% water. Samples were hermetically sealed and allowed to stand for 1 h at room temperature before heating in DSC. The DSC analyzer was calibrated using indium and an empty aluminum pan was used as reference. Sample pans were heated at a rate of 10 °C min^{-1} from 20 to 100 °C. Onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy of gelatinization (ΔH_{gel}) were calculated automatically.

Pasting properties of potato flours

The pasting properties of the freeze-dried potato flours were measured using a Rapid Visco analyser (Newport Scientific Pty Ltd, Warriewood, Australia). An aqueous dispersion of flour (6%, w/w; 25 g total weight) was heated from 60 to 95 °C at a heating rate of 6 °C min^{-1} (after an equilibration time of 1 min at 50 °C), held for 2.5 min, cooled to 50 °C at the same rate and again held at 50 °C for 2 min. Each sample was analyzed in triplicate.

Texture profile analysis of potato flour gels

A 10% aqueous suspension of flour from each potato cultivar was heated in a boiling water bath for

30 min with constant stirring. The paste was then poured into Petri dishes (50 mm diameter, 10 mm deep). After cooling at room temperature for 1 h, the paste was covered and then stored at 4 °C for 1–7 days. The texture profile of the flour gels was measured using an Instron universal testing machine using a 100 N load cell. A gel column (1 cm^3) was obtained from the middle portion of the gel and compressed with a cylinder-type probe (3.5 mm diameter) at 50% of the compression ratio where no gel fracture occurred. The crosshead speed was 1.0 mm s^{-1}. From the texture profile curve, hardness, cohesiveness, adhesiveness, springiness, gumminess and chewiness were calculated. TPA was performed on the gels prepared in triplicate for each cultivar.

Particle size analysis of starches

Starch was isolated from the potatoes of each cultivar as described earlier.[27] Starch yield was calculated as the amount of starch recovered per 100 g of potatoes and particle size analysis of the starches was done using a Coulter small volume module model LS230 laser light scattering particle size analyzer. A 0.25 g sample of potato starch was combined with 3 ml of distilled water in a small glass vial and vortexed, followed by sonication for 1 h. Dried sample was completely deagglomerated after approximately 10 min of sonication at 40 °C. The sample was vortexed and approximately 10 drops were added to the sample port until the instrument read 45% polarization intensity differential scattering (PIDS) or 10–14% obscuration. Isopropanol was used as the suspension fluid within the instrument. The sample was allowed to equilibrate in isopropanol for 15 min before starting the analysis.

Statistical analysis

The data reported in all the tables are an average of triplicate observations. The data were subjected to statistical analysis using Minitab Statistical Software (Minitab Inc, State College, PA, USA).

RESULTS AND DISCUSSION

Physicochemical, sensory and cooking characteristics of tubers

K Lalima showed the highest dry matter (24.7%), while it was lowest for K Ashoka (Table 1). Kunden and K Lalima potatoes showed higher starch yields (11.5 and 10.7%, respectively) and K Ashoka showed the lowest (7.9%). Cooked K Lalima and K Kunden also exhibited higher mealiness scores and showed high reflection of starch grains on surface in comparison to the other potato cultivars. Cooked K Dewa and K Bahar were firm, dry and less mealy in texture than K Kunden and K Lalima, as shown by the mealiness scores (Table 1). Cooked K Ashoka and K Kanchan appeared to be highly moist and soapy and showed least mealiness. Kaur *et al*[11] and O'Beirne *et al*[28] also reported that mealy potatoes have higher dry matter contents than the waxy potatoes. Potatoes from K Kunden and K Lalima cultivars with higher mealiness scores showed lowest cooking time (22 and 24 min, respectively; Fig 1). The compressive force of raw potatoes was observed to be higher for K Dewa and K Bahar, falling over 12 min of cooking by a factor of ∼11. K Ashoka and K Kanchan raw potatoes showed the lowest compressive force. K Dewa and K Bahar potatoes also exhibited lower water uptake and higher solubles in cooking water during cooking (data not shown).

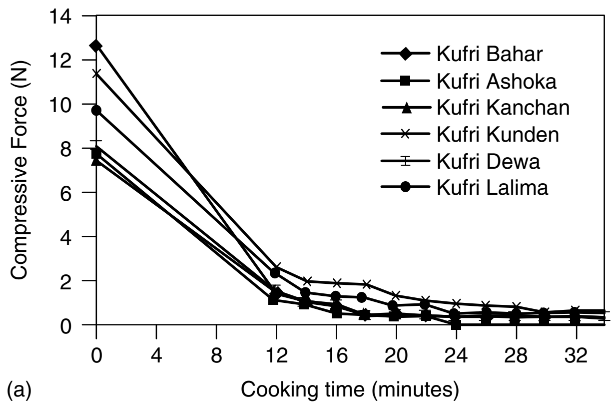
Color characteristics of raw tubers

Color is often the first parameter by which a consumer judges a food product before purchase. Hunter L^*, a^* and b^* values of fresh and stored cleaved potatoes from different cultivars varied significantly (Table 1). Freshly peeled tubers of K Dewa, K Lalima and K Bahar showed higher L^* and a^* values. K Kunden potatoes showed the highest b^* value (28.62), whereas K Kanchan and K Ashoka fresh cut potatoes showed the lowest (23.29 and 22.64, respectively). L^* and b^* values decreased while a^* values of cut potatoes from different cultivars increased during storage. K Ashoka peeled potatoes showed greater decrease in L^* value (indicative of darkening) and increase in a^* and b^* values (indicative of browning) during storage. K Dewa, K Lalima and K Bahar peeled and

Table 1. Physicochemical characteristics of potato tubers from different cultivars

				Color characteristics						
				L^*		a^*		b^*		
Cultivar	Dry matter content (%)	Starch yield (%)	Mealiness scores	0 min	After 30 min	0 min	After 30 min	0 min	After 30 min	ΔE
K Bahar	17.6b	8.8c	1.8c	72.1b	71.3c	−1.7b	−0.7b	24.2c	24.0b	2.0a
K Ashoka	15.4a	7.9a	0.7a	69.0a	64.0a	−2.4b	2.3d	22.6ab	20.8a	11.4d
K Kanchan	16.1a	8.2b	1.2b	68.8a	66.6b	−2.6b	0.4a	23.3b	22.5b	6.1c
K Kunden	18.5c	11.5f	3.0d	68.6a	66.7b	−2.8b	−0.2a	28.6d	27.8c	5.4b
K Dewa	2.4d	9.9d	2.0c	73.7c	73.6d	−2.2b	−0.8b	21.5a	21.4a	1.5a
K Lalima	24.7e	10.7e	2.8d	73.9c	73.6d	−2.1b	−1.2c	23.7b	23.6b	1.4a

Values with the same letter in a column did not differ significantly ($p < 0.05$).



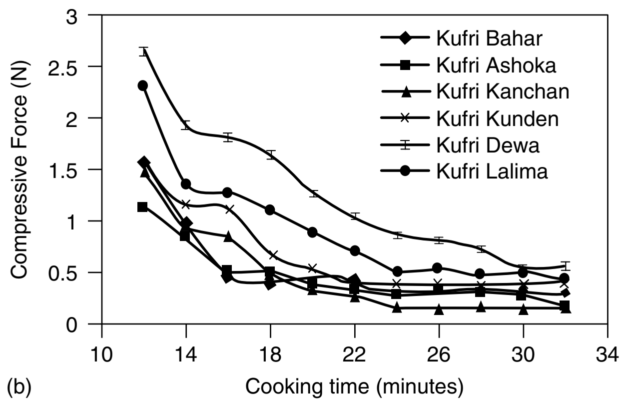


Figure 1. (a) Effect of cooking time on compressive force of raw potatoes. (b) Enlargement of the 10–34 min cooking time region.

cut potatoes showed lower darkening and browning during storage (Table 1). The combined change in the L–a–b values has generally been consolidated as a change in the total color difference [ΔE, equation (1)], since this represents a total of differences amongst the individual values. The changes in ΔE were observed to be greater for K Ashoka and K Kanchan potato tubers, whereas K Lalima and K Dewa showed the smallest changes. Talburt *et al*[29] have suggested that the differences in the color of fresh potatoes and the extent of browning among the potato cultivars may be due to the differences in the levels of *polyphenol oxidase*, phenolic compounds and concentration of pigments present in the tuber. A dark color not only affects the product quality but also affects its commercial value.

Microstructural features of raw tubers

In the potato specimens studied by SEM, the raw cell interior including the starch granules can be visualized. Figure 2(a) shows the microstructural features of raw tuber parenchyma of different cultivars. The potatoes from all the cultivars showed a reasonable preservation of the polygonal cell outline. Many cells were found to be cut open, revealing their contents, but many cells lost their starch granules during the chemical fixation procedure. Variation in cell sizes, shape of the cells and the granule sizes was the most obvious difference among the various cultivars. Variation in cell sizes in the specimens from different cultivars can be recognized from the micrographs—K Ashoka (E) and

Table 2. Mean granule diameter of starches, amylose content and transmittance of freeze-dried flour pastes during storage at 4 °C

Cultivar	Amylose content (%)	Mean granule diameter (μm)	Transmittance (%)		
			0 h	24 h	96 h
K Bahar	18.2c	24.7a	11.4a	11.2c	5.8a
K Ashoka	15.1a	31.0c	13.4ab	12.4c	8.0b
K Kanchan	15.2a	31.1c	14.2b	9.6b	6.0a
K Kunden	20.0d	30.5c	17.5c	16.3d	8.3b
K Dewa	16.3b	26.3b	11.9a	8.3a	5.8a
K Lalima	19.4d	29.9c	15.3b	11.3c	6.2a

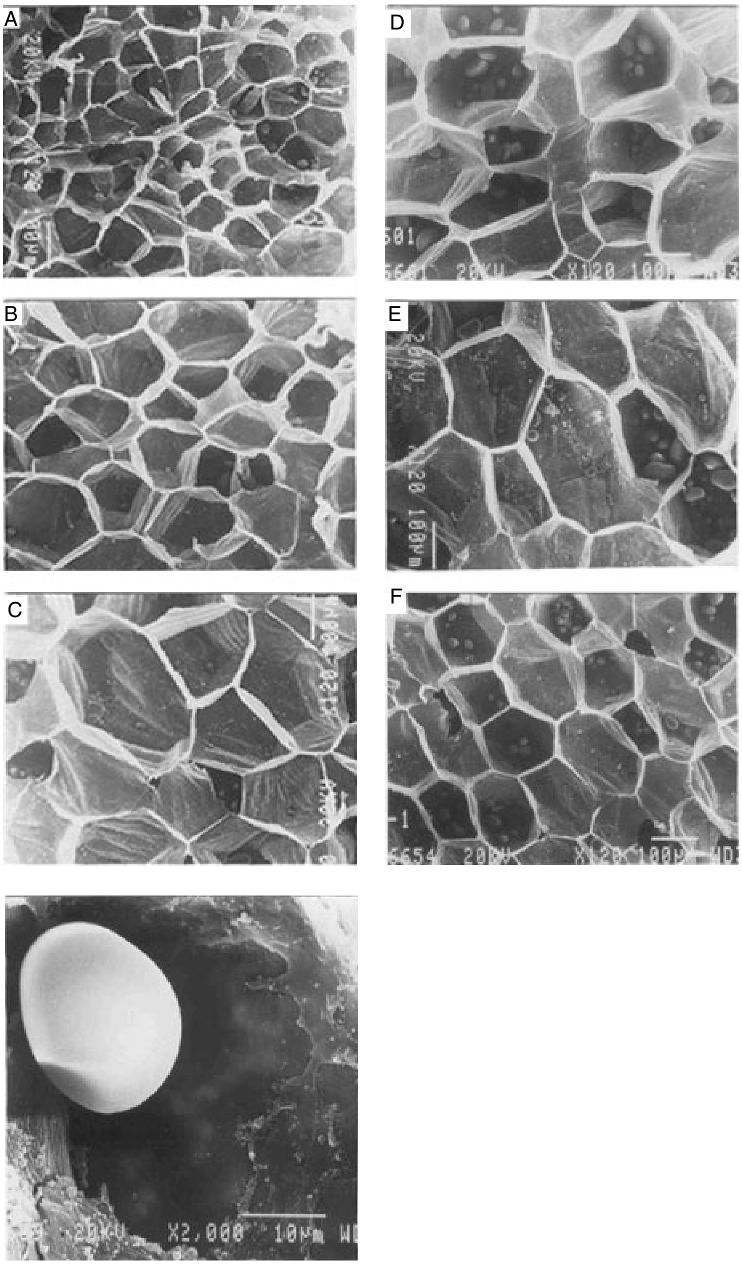
Values with the same letter in a column did not differ significantly ($p < 0.05$).

K Kanchan (F) with large cells (~200 × 340 μm) and K Bahar (A) with small cells (~80 × 90 μm). Being smaller in size, the cells from K Bahar (A) and K Dewa (B) appeared more numerous per micrograph compared with the other cultivars, thereby increasing the cell wall proportion per tuber in the former cultivar. Difference in the shape of the cells was another important feature in the potato cultivars studied. K Ashoka (E) and K Kanchan (F) tuber cells were elongated and hexagonal, whereas those of K Dewa and K Bahar were roughly spherical. K Ashoka (E) and K Kanchan (F) cells also showed a very regular arrangement of cells in contrast to K Bahar (A), which had cells of irregular shape. The different potato cultivars also appeared to differ in cell wall thickness. K Kunden (C), K Lalima (D) and K Dewa (B) tubers appeared to have thicker cell walls while K Ashoka (E) and K Kanchan (F) tubers appeared to have very thin cell walls. Each cell showed the presence of six to 10 mature (10–70 μm in diameter) and hundreds of immature tiny starch granules (0.5–1.0 μm in diameter). The latter seemed to be adhering to the cell walls when observed at a higher magnification [Fig. 2(b)]. Granule size varied with the starches isolated from the different cultivars. The particle size analysis of the starches from the different cultivars revealed that the potatoes with large-size cells exhibited larger mean starch granule size, and vice versa (Table 2). The starch granules from the different cultivars ranged in size from 1 to 70 μm. Starches from K Bahar (A) and K Dewa (B) potatoes had a smaller mean granule size than those from the other cultivars.

Textural characteristics of tubers

The parameters derived from the textural profile analysis curves for raw and cooked potatoes are given in Tables 3 and 4. Among the raw potatoes from different cultivars, K Dewa and K Bahar tubers showed higher fracturability (FR), hardness (HA) and cohesiveness (CO), whereas K Ashoka and K Kanchan tubers showed lower values for these parameters. FR and HA were significantly negatively correlated with granule size ($r = -0.786$ and -0.865, respectively). The

(a)



(b)

Figure 2. (a) Scanning electron micrographs of fracture surface of raw potato parenchyma from different cultivars: (A) K Bahar; (B) K Dewa; (C) K Kunden; (D) K Lalima; (E) K Ashoka; and (F) K Kanchan ($\times$120, bar = 100 µm). (b) Scanning electron micrographs of a fracture surface of raw potato at $\times$2000, showing single mature starch granule along with hundreds of immature tiny starch granules adhering to the cell walls (bar = 10 µm).

differences in the textural behavior of the raw tubers may be due to the differences in their microstructure. Potatoes with closely packed cell arrangement (K Dewa and K Bahar), small size and irregular cells (K Bahar and K Dewa) with smaller mean starch granule size (K Bahar and K Dewa) and higher starch content (K Kunden and K Lalima) were observed to be much harder and more cohesive. In contrast, potatoes with loosely packed cell arrangement, and large size cells (K Ashoka and K Kanchan) were found to be less hard and cohesive. The small size cells and higher proportion of cell walls may be responsible for the higher HA and CO of K Bahar and K Dewa potatoes. The lower HA of K Ashoka and K Kanchan potatoes could also be explained on the basis of their dry matter content, although the correlation of dry matter with hardness was not significant. This variation mostly discriminated between the cultivars, K Ashoka and K Kanchan having huge starch grains, lower starch content and dry matter content and K Dewa and K Dewa having higher values for most of the TPA measures. K Bahar and K Dewa potatoes showed higher gumminess (GU) and chewiness (CH) values followed by K Kunden and K Lalima potatoes with higher mealiness scores. Least mealy cultivars K Ashoka and K Kanchan potatoes showed exceptionally low values for these parameters. Among the potato cultivars studied, K Kanchan raw potatoes exhibited the lowest springiness (0.0018 m) and K Lalima showed the highest (0.0029 m). Raw potatoes from all the cultivars were observed to have a non-adhesive character. Among the cooked potatoes from different cultivars,

Table 3. Texture profile analysis parameters of raw potatoes from different cultivars

Cultivar	Fracturability (N)	Hardness (N)	Cohesiveness	Springiness (m)	Gumminess (N)	Chewiness (J)
K Bahar	123d	183d	0.125e	0.0024b	22.88d	0.055d
K Ashoka	85a	104a	0.067b	0.0026b	6.97b	0.018b
K Kanchan	81a	92a	0.053a	0.0018a	4.88a	0.009a
K Kunden	106b	154c	0.095c	0.0027b	14.63e	0.040c
K Dewa	119c	187d	0.119de	0.0025b	22.25d	0.056d
K Lalima	116c	127b	0.11d	0.0029b	13.97c	0.041c

Values with the same letter in a column did not differ significantly ($p < 0.05$).

Table 4. Texture profile analysis parameters of cooked potatoes from different cultivars

Cultivar	Fracturability (N)	Hardness (N)	Cohesiveness	Adhesiveness (J)	Springiness (m)	Gumminess (N)	Chewiness (J)
K Bahar	3.8d	8.5e	0.11b	1.97×10^{-4}b	0.0012bc	0.93c	0.0011d
K Ashoka	2.7b	4.5b	0.068a	1.72×10^{-4}a	0.0010ab	0.31b	0.0003a
K Kanchan	1.8a	3.1a	0.072a	1.56×10^{-4}a	0.0009a	0.22a	0.0002a
K Kunden	3.4c	6.9c	0.083a	2.74×10^{-4}d	0.0010ab	0.57c	0.0006b
K Dewa	4.1d	7.3d	0.10b	2.16×10^{-4}c	0.0011abc	0.73d	0.0008c
K Lalima	3.2bc	7.3d	0.077a	2.35×10^{-4}c	0.0013c	0.56c	0.0007c

Values with the same letter in a column did not differ significantly ($p < 0.05$).

K Bahar, K Dewa potatoes showed higher FR, HA and CO followed by K Kunden and K Lalima potatoes, whereas potatoes from the least mealy K Ashoka showed exceptionally low values for these parameters. The texture of cooked potatoes depends on the cooking conditions as a result of various factors such as starch gelatinization, pectin degradation, cell wall breakdown, cell wall separation, etc. Kaur *et al*[11] have reported higher FR, HA and GU for mealy potatoes. A positive correlation between tuber starch content and dry matter content with reflection, graininess, mealiness, adhesiveness and chewiness of cooked potato has also been reported earlier.[6] Adhesiveness (AD) was found to be higher for K Kunden and K Lalima potatoes, which may be due to the higher amylose content in the starches of these potatoes.

Physicochemical characteristics of flours

The amylose content of potato flours from different cultivars ranged from 15.1 to 20.0%. The amylose content is one of the important factors affecting the starch pasting and retrogradation behaviour.[30] Among the potato flours, K Kunden and K Lalima flour had the highest amylose content, whereas K Ashoka and K Kanchan had the lowest (Table 2). The WAI of all the potato flours also differed to a significant extent. K Kunden and K Lalima potato flours showed highest WAI while it was lowest for K Dewa and K Kanchan (data not shown). The water uptake of the potato solids has been reported to be mainly due to the swelling and gelatinization of the starch granules.[15] When starch is gelatinized at a certain temperature, molecular organization is disrupted within the granule, and the starch–water interactions increase, resulting in a substantial increase in the swelling.[31] Molecular structure of starch, including crystalline structure and chemical composition, could also influence the water absorption capacity of the flours.[32] K Kunden and K Lalima flour pastes also showed higher transmittance, whereas K Bahar and K Dewa showed the lowest transmittance (Table 2). The differences in transmittance may be due to the difference in the levels of starch granule/cell wall remnants present in the K Kunden and K Lalima flour pastes, which in turn depend on the microstructure of the tuber tissue and the morphological features of the starch granules. The higher cell wall proportion per unit area in K Dewa and K Bahar tubers may be responsible for the formation of more turbid flour pastes, thereby decreasing transmittance. Moreover, as shown by the particle size analysis (Table 2), K Dewa and K Bahar starches exhibited smaller size starch granules, which may also be responsible for the lower transmittance of their pastes. The starch pastes having a greater number of large size granules contain less granule remnants, which allow the light to pass through instead of being refracted and scattered and exhibited higher light transmittance.[27,33] The transmittance decreased progressively during refrigerated storage of the flour pastes. The granule swelling, granule remnants, leached amylose and amylopectin, molecular weights and chain lengths of amylose and amylopectin have been reported to vary with the granule size, which ultimately leads to the turbidity development and decreased light transmittance in the starch pastes during refrigerated storage.[34] K Ashoka and K Bahar flour pastes showed smaller decreases in transmittance during storage. The differences in the amylose and phosphorus contents among the various potato starches may also have affected the light transmittance values of the pastes.[35]

Thermal and pasting properties of flours

Thermal properties of the flours from different cultivars varied to a significant extent (Table 5). Gelatinization and retrogradation of starch are chiefly

Table 5. Thermal and pasting properties of freeze-dried flours from different potato cultivars

	Thermal properties				Pasting properties						
Cultivar	T_o (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J g^{-1})	Pasting temperature (°C)	Peak viscosity (RVU)	Trough (RVU)	Breakdown (RVU)	Setback (RVU)	Final viscosity (RVU)	Setback ratio
K Bahar	55.6a	61.6a	67.5a	11.3c	66.5a	343ab	177b	166b	140b	317b	1.8b
K Ashoka	57.8b	63.7b	68.8bc	9.5a	67.6b	328a	145a	183c	107a	252a	1.7ab
K Kanchan	61.6c	65.4c	69.3c	9.6a	68.1c	346ab	158a	188c	108a	266a	1.7a
K Kunden	55.7a	61.9a	67.3a	9.7a	66.7a	419c	245d	144a	207c	482d	2.0c
K Dewa	56.0a	62.2a	67.0a	11.6c	66.9ab	351ab	202c	149a	156b	358c	1.8b
K Lalima	55.8a	62.4a	67.9ab	10.4b	67.2b	376b	221c	155ab	168b	389c	1.8b

T_o = onset temperature; T_p = peak temperature; T_c = conclusion temperature; ΔH_{gel} = enthalpy of gelatinization (dwb, based on starch weight). Values with the same letter in a column did not differ significantly ($p < 0.05$).

responsible for the endothermic transitions in the potato dry matter. Starch granules from the mealier potatoes gelatinized at significantly lower temperatures compared with those from the less mealy potatoes. Pasting properties of flours from all the six potato cultivars are presented in Table 5. The pasting temperature of flours from different potato cultivars ranged between 66.5 and 68.1 °C. The pasting temperatures for potato flours from various cultivars were observed to be ~1 °C lower than their respective conclusion temperatures of gelatinization measured using DSC. K Kunden and K Lalima flours showed peak viscosity of 419 and 376 RVU, respectively whereas K Ashoka flour exhibited the lowest peak viscosity of 328 RVU. Flours from the mealier cultivars K Kunden and K Lalima showed the highest final viscosity (482 and 389 RVU, respectively). K Ashoka flours exhibited the lowest final viscosity (252 RVU). K Kunden and K Lalima (mealy type) flour pastes exhibited higher setback, whereas those of the least mealy types showed lower setback, which could be a result of lower retrogradation/aggregation of amylose in the latter on cooling. *Setback ratio* is defined as the ratio of final viscosity to trough viscosity[36] and is usually used to predict the retrogradation tendency of starch or starchy materials.[37] Retrogradation is of considerable practical importance since it affects textural changes in starchy foods. The setback ratios of K Kunden potato flour paste was the highest followed by K Lalima and K Dewa flour pastes. Breakdown and setback have been reported to have a close association with the amylose content. Amylose content was positively correlated with the setback ($r = 0.784$) and negatively correlated to breakdown ($r = -0.769$). Reassociation during cooling was poor in low amylose starches while high amylose starches showed higher setback. The differences in the pasting properties of flours from different cultivars may be due to the difference in the granular size, phosphorus content and amylose content of the starch granules.[30]

Textural characteristics of flour gels

The starch gels were mechanically tested for texture profile (HA, CO, AD, GU, CH) and springiness (SP) after storage for 1, 3 and 7 days at 4 °C. HA, GU, CH and SP of flour gels from all the potato cultivars increased during storage, whereas the reverse trend was observed for AD (Table 6). During storage, the starch molecules rearrange, thus stiffness and rigidity of the granules increase.[38] Among the different cultivars, K Bahar and K Kanchan flour gels displayed gel hardness of 2.6 and 1.7 N, respectively, after one day of storage, which increased to 4.5 and 3.4 N after 7 days of storage. This increase is due to the retrogradation of starch molecules, which in turn depends on aggregation of amylose and amylopectin molecules.[39] K Ashoka and K Kanchan flour gels displayed significantly lower HA, CH, GU and SP, and higher AD, regardless of the storage period. K Ashoka and K Kanchan flour gels exhibited higher AD of 3.34×10^{-3} and 2.94×10^{-3} J, respectively after 1 day of storage, which decreased to 1.73×10^{-3} and 2.37×10^{-3} J, respectively after 7 days of storage.

Table 6. Textural properties of flour gels stored at 4 °C for 1 and 7 days

	Hardness (N)		Cohesiveness		Adhesiveness (J)		Gumminess (N)		Chewiness (N)		Springiness	
Cultivar	1	7	1	7	1	7	1	7	1	7	1	7
K Bahar	2.6c	4.5c	0.3a	0.4ab	2.61×10^{-3}c	2.04×10^{-3}d	0.8c	1.7b	0.8bc	1.7b	0.9b	1.0b
K Ashoka	1.9ab	2.8a	0.4a	0.4ab	3.34×10^{-3}e	1.73×10^{-3}c	0.7b	1.1a	0.2a	0.4a	0.3a	0.4a
K Kanchan	1.7a	3.4b	0.3a	0.3a	2.94×10^{-3}d	2.37×10^{-3}e	0.6a	1.2a	0.2a	0.5a	0.4a	0.4a
K Kunden	2.1b	4.2c	0.3a	0.4b	1.84×10^{-3}a	1.56×10^{-3}a	0.6b	1.7b	0.6b	1.6b	0.9b	1.0b
K Dewa	2.6c	3.6b	0.5b	0.5c	2.27×10^{-3}b	1.63×10^{-3}b	1.2d	1.9b	1.1d	1.9b	0.9b	1.0b
K Lalima	2.6c	4.7c	0.4a	0.4b	2.71×10^{-3}cd	2.34×10^{-3}e	0.9c	1.8b	0.8c	1.7b	0.9b	1.0b

Values with the same letter in a column did not differ significantly ($p < 0.05$).

Hardness of the flour gels was observed to be positively correlated to amylose content.

CONCLUSION

In conclusion, the cooking and textural characteristics of tubers from different potato cultivars were found to be linked to their microstructural features. K Ashoka and K Kanchan potatoes with lower mealiness scores, amylose content, loosely packed cell arrangement, and with comparatively larger cells, showed lower hardness, cohesiveness, springiness, chewiness, gumminess and longer cooking time. Potato flours with lower pasting and gelatinization temperatures showed higher peak viscosity, setback, final viscosity and lower breakdown in viscosity.

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